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ORIGINAL PAPER

Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javanrood County in Iran

H. Karimi[1] · S. Amiri[2] · J. Huang[3] · A. Karimi[4]

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Abstract
The current study presents the integration of geographical information system (GIS) and multi-criteria decision analysis (MCDA) for municipal landfill site selection, a case example in Iran. In the first step, useful criteria were determined based on the literature review, national standards and regulations, expert opinion, data availability and regional characteristics. Several criteria including distance from groundwater resources, distance from surface water, distance from urban and rural areas, distance from protected areas, land use, distance from faults, distance from roads and the slope were selected, and a hierarchical structure was formed for landfill suitability. The maps of the criteria were prepared using ArcGIS 10.2. Using different fuzzy membership functions, the maps were standardized. An AHP-based pairwise comparison was applied to calculate the weights of the parameters, and standardized maps were overplayed using the weighted layer combination approach to gain the landfill suitability map in the study area. The final map was assorted into four suitability classes, i.e., high, moderate, low and unsuitable regions. The result indicates that almost 92% of the study area is inappropriate and cannot be considered as landfill. The comprehensive field visits were performed to further assessment, and finally, three candidate sites were suggested. The result illustrated that an integrating approach of GIS and MCDA is effective in landfill site selection.

Keywords Municipal solid waste · Landfill · GIS · MCDA · WLC

Introduction

One of the crucial environmental problems related to municipal solid wastes (MSW) is solid waste management that is a primary concern to city managers and municipalities. Municipal solid waste comprises items such as product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics and batteries that generate from homes, institutions, hospitals and commercial sources (EPA 2016; Pichtel 2005). The problem of municipal solid waste in regions such as developing countries is severe because of urban expansion, poor planning, the lack of solid waste management practice and inadequate resources contributed to the poor state (Ferronato et al. 2017). Most of the developing countries generally deposit their MSW in open or excavated landfills, accompanied by open burning to reduce waste volumes (Ferronato et al. 2017).

Effective management of MSW requires a good understanding of the quality and the quantity of the waste, the economic cost of operation and environmental impacts of treatment methods (Chandrappa and Brown 2012). Recycling, composting and landfilling are the most common methods for municipal solid waste management (Chandrappa and Brown 2012; Ludwig et al. 2003). The combination of these management techniques is utilized to manage municipal solid wastes, but the existence of sanitary landfill could not be ignored in an MSW management system (Kharlamova et al. 2016; Santhosh and Sivakumar 2018). Sanitary Landfill is a conventional method for municipal wastes because

Editorial responsibility: Binbin Huang.

✉ H. Karimi
hazhir.karimi25@gmail.com

1 Department of Geotechnical, Faculty of Engineering, Koya University, Kurdistan Region, Iraq

2 Expert of Environment and Water Quality Bureau, Deputy for Conservation and Operation, Kermanshah Regional Water Authority, Kermanshah, Iran

3 Coastal and Ocean Management Institute, Xiamen University, Xiamen 361005, China

4 Islamic Azad University, Science and Research Branch, Tehran, Iran

of the construction cost and simple operation, and it is an inevitable element of MSW systems (Khorram et al. 2015; Rahmat et al. 2017).

Inappropriate landfills have significant environmental problems on the environment components such as water resources, soil fertility, natural habitats, and landscape view (Al-anbari et al. 2014; Feo and Gisi 2014; Kapilan and Elangovan 2018). To reduce the adverse effects on the environment, it is necessary to consider all environmental standards in selecting places for landfills. Also, social and economic factors play an essential role in selecting landfills because of the costs and financial expense as well as social conflicts (Eskandari et al. 2012; Santhosh and Sivakumar 2018; Khan et al. 2018). The various environmental, social and economic parameters make a complicated process in landfill site selection, and it is difficult to aggregate and analyze different factors and show the outcomes obviously (Karimzadeh Motlagh and Sayadi 2015; Barakat et al. 2016).

Geographic information system (GIS) has abilities to manage a large volume of spatial data and analyze the data effectively (Karimzadeh Motlagh and Sayadi 2015; Gbanie et al. 2013; Sieif et al. 2016). However, GIS has some limitations in choosing the various criteria and options, relative importance and ranking the final options (Malczewski 2004). Multi-criteria decision analysis (MCDA) offers a combination of different options, as a collection of techniques considering different criteria and their weights (Malczewski 2004; Li et al. 2018). The MCDA includes a complex of a designed method for recognition and organizing the related information with different levels in complicated processes of decision making and is the most effective tool when there are various criteria and objectives (Asgharpour 2009; Malczewski 2004).

Integrating MCDA and GIS creates an advantageous method that manages the time and costs of the analysis, reduces the errors and increases the accuracy of the decision making (Gorsevski et al. 2012; Vučijaka et al. 2016). Moreover, this combination can be used for a vast range of spatial tasks and provide solutions for the problems in environmental sensitivity analysis. An integrating approach of the GIS and MCDA has widely been used in landfill site selection studies (Moeinaddini et al. 2010; Eskandari et al. 2012; Gorsevski et al. 2012; Nazari et al. 2012; Alavi et al. 2013; Gbanie et al. 2013; Feo and Gisi 2014; Ashraf et al. 2015; Karimzadeh Motlagh and Sayadi 2015; Rahmat et al. 2017; Bahrani et al. 2016; Aksoy and San 2017; Barakat et al. 2016; Kahraman et al. 2017; Victor et al. 2017; Al-Anbari et al. 2018; Khan et al. 2018; Santhosh and Sivakumar 2018; Yildirim et al. 2018; Demesouka et al. 2019).

The current research aimed to use the application of geographic information system and multi-criteria decision analysis for landfill site selection. Javanrood County located in the west of Iran was selected as a case example for this study. Also, a zonation of the study area for landfill sites and prioritization of appropriate locations were prepared. The current site to dispose the municipal waste in Javanrood has an inappropriate place and the wastes burry through an open dumping, resulting in creating various environmental problems to the surrounding natural environment and Javanrood City. Given the potential adverse environmental impacts linked to the waste disposal in Javanrood, there is a significant need to accelerate in identifying the most suitable site and developing the controlled municipal landfill.

Case study

The case study is the part of Javanrood County in the north of the Kermanshah Province, west of Iran (Fig. 1). Case study covers a total area of a 43,180 ha. The total population of the study area and Javanrood City are around 80,000 and 45,000 in 2015, respectively (National Census Organization 2015). The climate of the region is semi-humid, where average annual rainfall and average temperature have been recorded 400 mm and 15 °C, respectively. Prominent land use/land cover types of the study area are dense forest, woodlands, agriculture and residential areas. The primary sources of inhabitants' income are agriculture, business and livestock, while economic growth in the region has led to a substantial increase in population, urban expansion and generation of municipal solid wastes. The daily waste generation is approximately 80 tons per day which dry wastes consist of 50 percent, and the other half belongs to wet wastes. Wastes gather regularly by the manicipality and bury in an unsanitary way in a open area.

Materials and methods

The integration of GIS and multi-criteria decision analysis process was used to identify the best available locations for a new municipal solid waste landfill in Javanrood in Iran. The whole explanation of the performed methods is described step by step in the following. Indeed, brief descriptions of the methodology are shown in Fig. 2. As it can be seen from the figure, the first stage is the selection of criteria based on related studies, national regulations and standards,

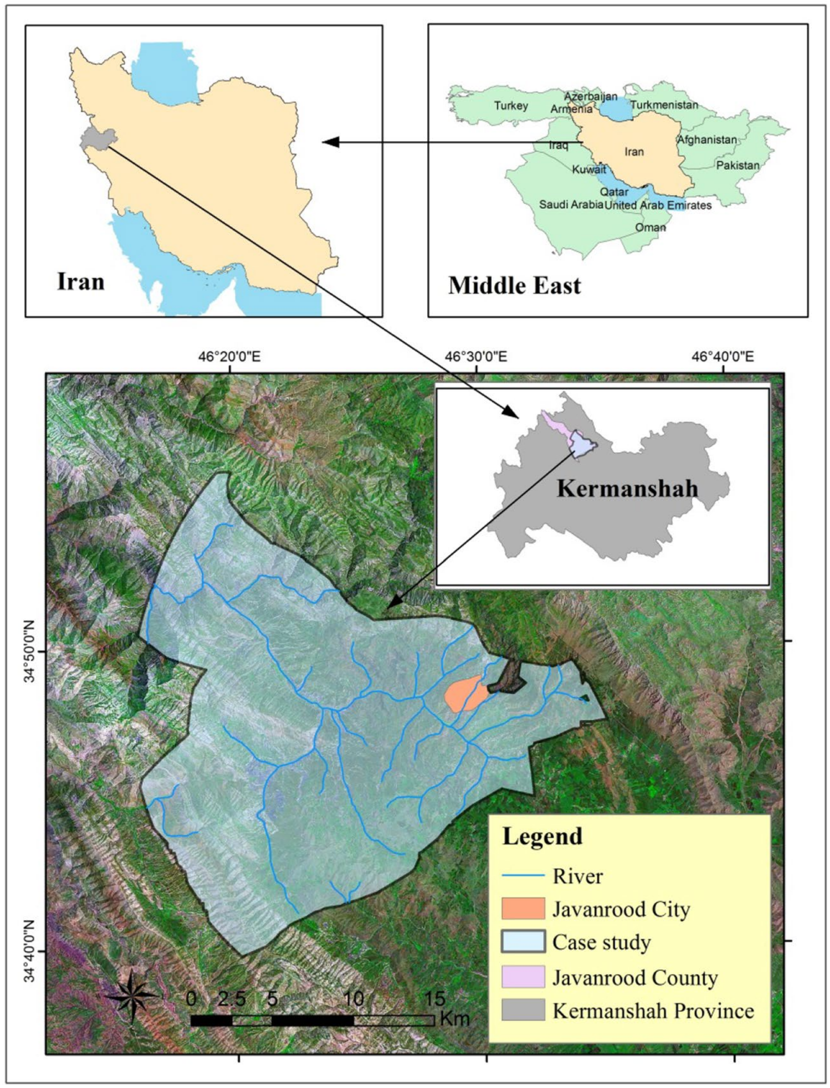

Fig. 1 Study area

expert opinion, data availability, and local characteristics. The information layers of the criteria were prepared using ArcGIS10.2. All information layers were standardized to a byte level range of 0–255 in which a scale of 0 was assigned to the unsuitable areas and scale of 255 was assigned to the most suitable regions for landfill. There is four fuzzy set membership function in IDRISI consist of sigmoidal, J-shape, linear and user-defined (Eastman 1993). Fuzzy set memberships and control points used in this study were selected from literature reviews (Aydi et al. 2013; Gorsevski et al. 2012; Khorram et al. 2015; Rezazadeh et al. 2014; Kharat et al. 2016) and expert opinion. Then, using AHP-based pairwise comparison the weights for criteria were calculated, and finally, standardized maps were overplayed using the weighted layer combination (WLC) method to obtain the landfill suitability map in the study area. The whole explanation of the performed stages is described in the following.

Determining criteria and data collection

The first fundamental step in site selection was the determination of criteria to assess the suitability of land to gain the objectives. In this study, criteria were selected based on literature review (Marin et al. 2012; Karimzadeh Motlagh and Sayadi 2015; Rahmat et al. 2017; Bahrani et al.

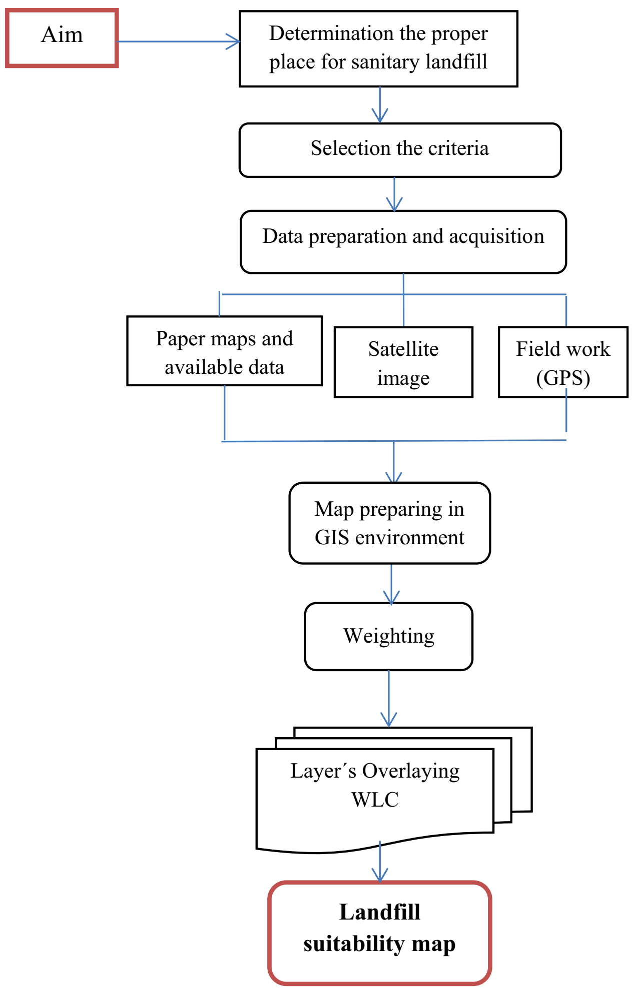

Fig. 2 Flowchart of the methodolofy

2016; Kahraman et al. 2017; Victor et al. 2017; Khan et al. 2018), national regulations and standards (Department of the Environment 2011), data availability, regional characteristics and expert opinion. Eight criteria were selected and classified into the main group (Fig. 3). The first group was environmental criteria which include distance to surface water resources, distance to groundwater resources, land use/land cover, distance to faults, distance to residential areas, distance to protected areas, geology and aspect. The second group was economic criteria and comprises distance to roads and slope. The data mainly acquired from field surveys, satellite images, 1:50,000 scale topographic maps, 1:100,000 scale geological maps, and available statistics and the information from organizations.

Criteria preparation and standardization

Environmental criteria

Distance from surface waters resources

Landfill sites are a potential threat for surface water resources through the movement of leachate and erosion waste. It is always ideal to locate landfills far away from surface water bodies (lakes, ponds, rivers, etc.) as far as possible. Department of the Environment of Iran (2013) and Iran Water Resources Management Company (2013) approve a minimum distance of landfills to water resources. They constituted that landfills should be established at least 750 m far from surface water resources. The map of the surface water resources was prepared from satellite images (Landsat 2015) and 1:50,000 topographical maps. A 750-m buffer zone was considered around the surface water bodies. This factor was standardized using a linear decreasing fuzzy function by two control points: distances less than 700 m are not suitable and distances more than 2000 m are the most suitable (Table 1, Fig. 4).

Distance from groundwater resources

The landfill sites create severe environmental effects on aquifer and groundwater resources. The type of leachate, the depth of buried waste and its coverage affect the groundwater resources. The geographic coordinate system of wells, springs and aqueducts were obtained from Water Resources Organization (2015). A 400-m buffer zone was considered around the groundwater resources. The GIS layer of this parameter was prepared and standardized using a linear decreasing fuzzy function by two control points: distances less than 400 m are not suitable and distances more than 800 m are the most suitable regions (Table 1, Fig. 4).

Distance from residential areas

The importance of the residential regions must be considered before landfill sitting because of the odors, noise, health concerns, property value and atheistic points. The layer of the residential areas was extracted from satellite image (Landsat ETM$^+$ 2015). The linear decreasing fuzzy function was applied for standardization of this factor, assigning high suitability to the distances more than 3000 m from cities, and unsuitable regions to the distances less than 3000 m. Also,

Fig. 3 Hierarchy of the selected criteria for landfill site selection

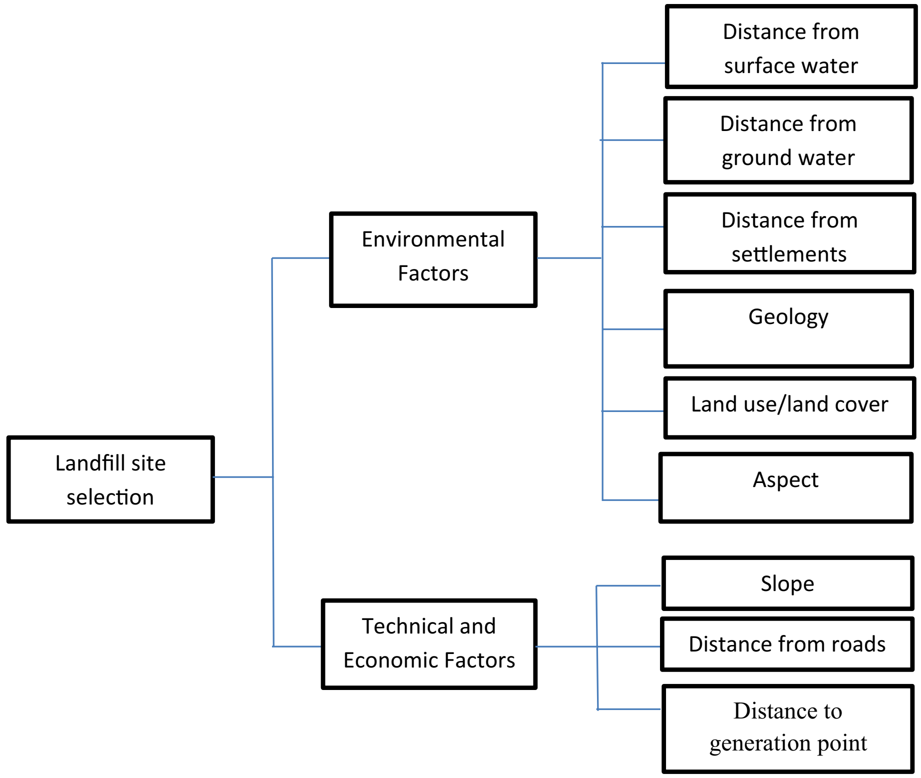

Table 1 Fuzzy set memberships and membership functions with control points used for landfill site selection

Criteria	Factors	Membership function	Control points	
Environmental criteria	Distance to surface waters resources	Linear increasing	750 m	2000 m
	Distance to groundwater resources	Linear increasing	400 m	800 m
	Distance to villages	Linear increasing	1500 m	3000 m
	Distance to cities	Linear increasing	3000 m	10,000 m
	Geology	–	–	–
	Distance from City	Sigmoidal	3000 m	20,000 m
	Distance from settlements	Linear increasing	750 m	1500 m
	Land use	–	–	–
Economic criteria	Distance from roads	Sigmoidal decreasing	b: 200 d: 2000	a: 80 c: 1000
	Slope	Linear decreasing	a: 10%	b: 25%

the 1500 m distance was considered for villages as unsuitable regions, and 3000 m as most suitable areas (Table 1, Fig. 4).

Geology

The type and thickness of bedrock and geological genus should be taken into consideration in landfill sites. Limestones and clay lands are inefficient for landfills because of wide gaps and high permeability, while metamorphic rocks have dual behavior according to their source and are suitable (Barakat et al. 2016). The geological maps 1:100,000 scale of the study area were digitized, and the vector layer of the geology was prepared. Regions that have poor geological conditions were given lower scores, an indication of its poor suitability, while those that are deemed ideal were given higher scores (Fig. 5).

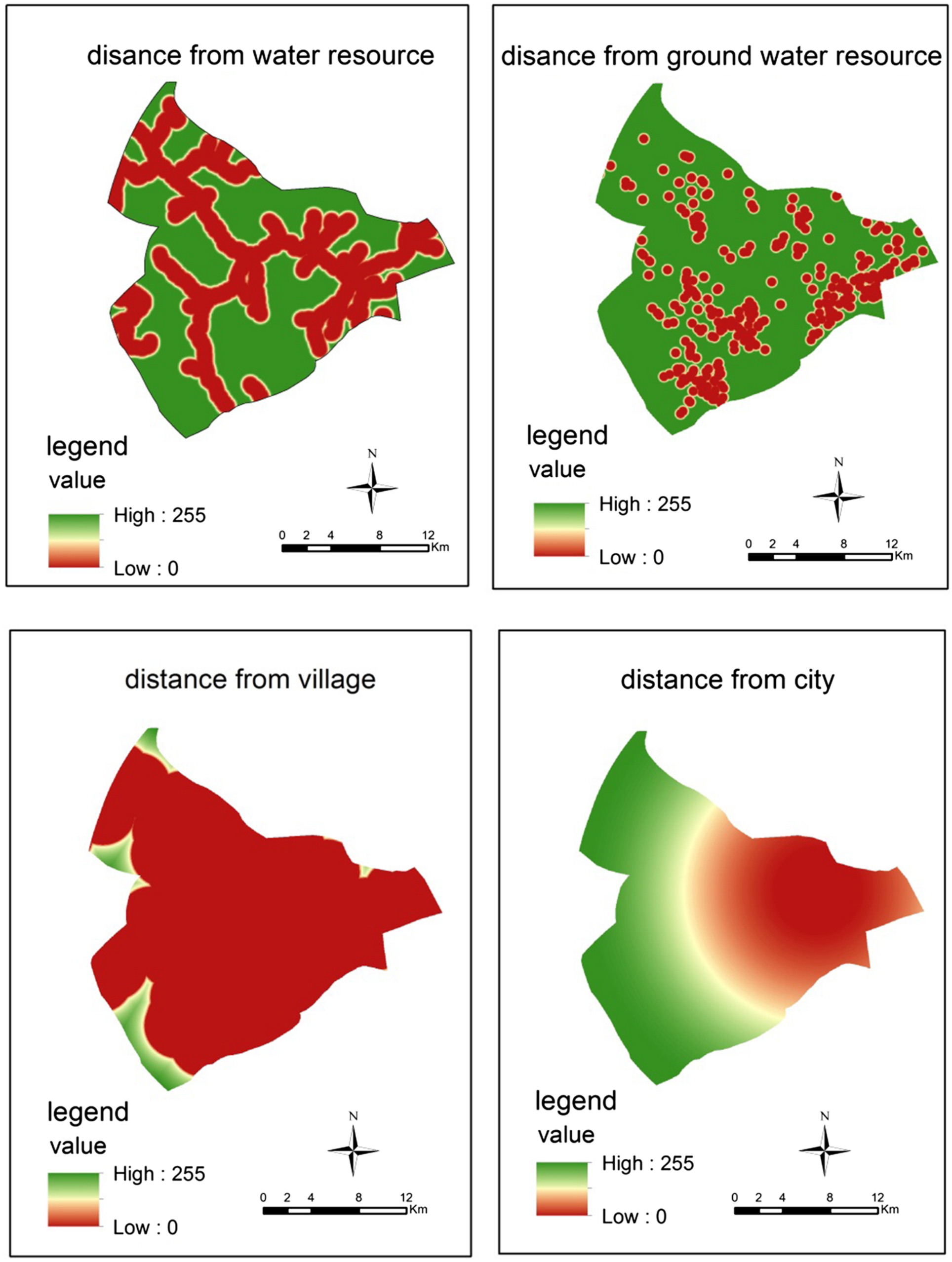

Fig. 4 Fuzzy maps: distance from surface water resources, groundwater resources, villages, cities

Land use

Some lands such as protected areas, dense forests, first class farmlands, residential areas and water bodies cannot be used as a landfill. Land use map has been prepared from Landsat images (2015). The Landsat ETM+ images were obtained and imported into IDRISI 32, geo-registered to the other layers and re-sampled to 30 m resolution. Then the images were classified using the maximum likelihoods supervised classification method. Seven classes were identified. Agriculture, forests, good pastures, urban areas and water bodies were considered to be less suitable, while places deemed ideal for the landfill sites were poor pastures and bare lands (Fig. 5, Table 2).

Aspect

Landfills potentially have adverse effects because of emissions of unpleasant odors and pollutants carried by the wind. Especially these negative impacts rise significantly when

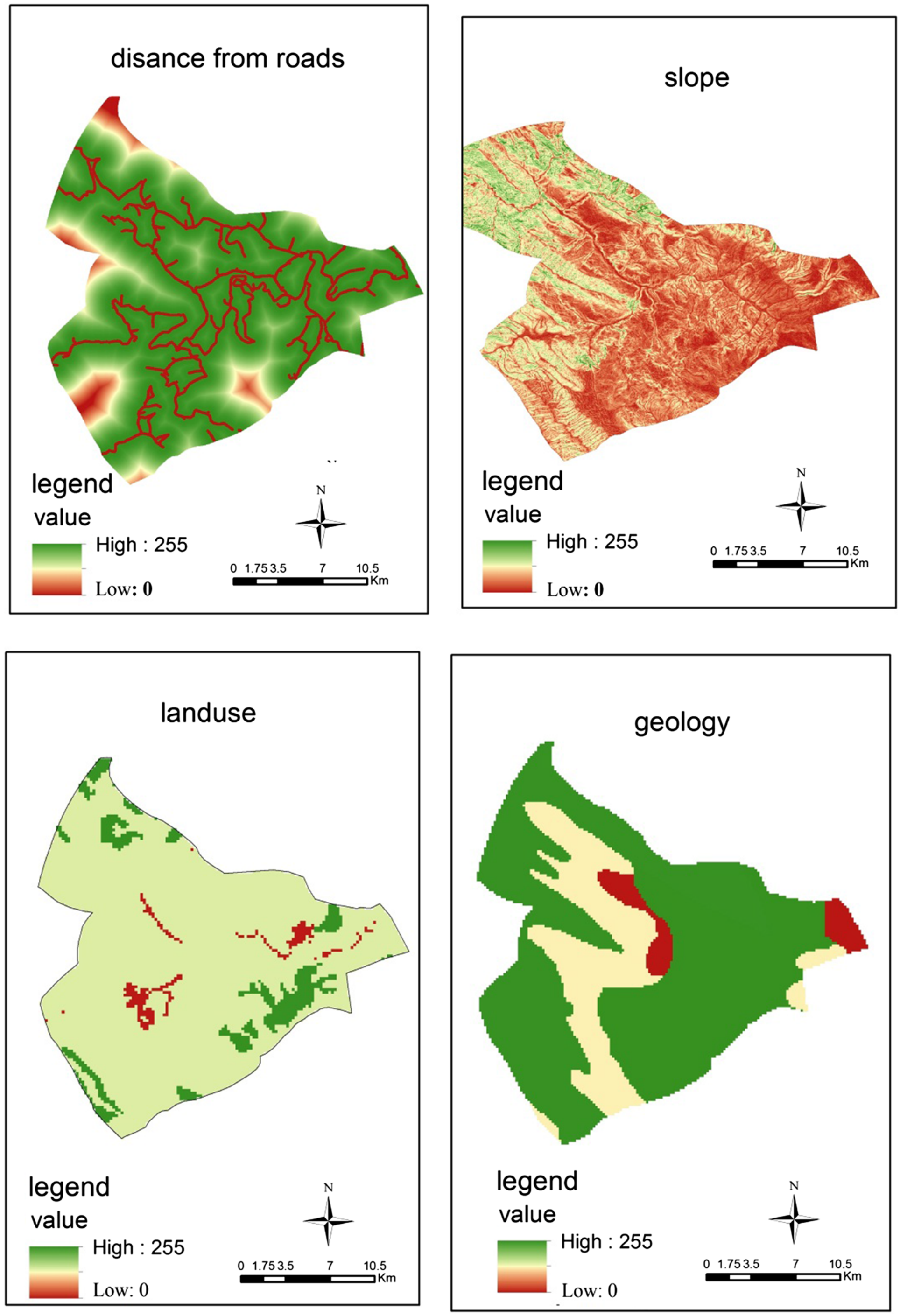

Fig. 5 Fuzzy maps: distance from roads, slope, geology, land use

the prevailing wind direction blows toward residential areas. Therefore, it is necessary to consider predominant wind direction in landfill site selection. Here, the aspect map was prepared using a digital elevation model (DEM) with a 30 m resolution. Western (W) and southeastern (SE) directions were the predominant wind direction in the study area, therefore, given the lowest value of the suitability, while the higher value of suitability was assigned to the other directions.

Table 2 Saaty and Vargas preference scales

Intensity of importance	Description
1	Equal importance
2	Equal to average importance
3	Average importance
4	Average to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong or super strong importance
9	Super strong importance

Table 3 Weighting the criteria using AHP method

Parameters	Weight
Land use	0.11
Distance from city	0.12
Distance from villages	0.11
Distance from roads	0.09
Distance from surface water resources	0.13
Distance from ground water resources	0.13
Slope	0.09
Aspect	0.1
Geology	0.12
Consistency rate: 0.04	

Economic criteria

Distance from roads

Landfill site should be close to roads network because of the construction and transportation costs. The national laws do not specify minimum distances of the landfill sites to the roads. However, in this study, considering environmental concerns a 200-m buffer for roads was considered. Road layer was extracted from 1:50,000 scale topographical maps and Google earth. Decreasing J-shape fuzzy function was used for standardization in which distances more than 200 m, and less than 1000 m are the most suitable, whereas distances more than 1000 m and less than are low suitable (Fig. 5, Table 2).

Slope

The slope is one of the most critical factors in locating a suitable place for a landfill in the aspects of the construction costs and land preparation. Slope also plays an essential role in water maintenance in the soil, runoff rate and erosion's potential. By the way, construction in areas with high slope is not economically ideal. Thus, the maximum suitable slop for the landfill was considered 20%. The map of the slope was prepared using the DEM with a 30 m resolution, in which slopes less than 25% were taken as the highly suitable and had been given the highest score (Table 2, Fig. 5).

Weighting criteria

In the next stage, the weight of criteria was determined to clarify the importance of the criteria. To determine the weight of factors which have unequal importance, the analytical hierarchy process (AHP), one of the most efficient techniques presented by Saaty (1977), was used. In the AHP, the weight of parameters is determined by three stages. First, the decision-making problem was divided into three levels including objective, criteria and sub-criteria. The objective was landfill suitability map; criteria and sub-criteria were explained in detail above. In the second step, the relative importance of criteria at each level was assigned. The pairwise comparison was made using expert's views by assigning a 9-point score from 1 to 9 (Table 2). All scores assigned from expert were imported into Expert Choice software, and the final weight of each criterion was obtained. The calculated weights are within the range of 0–1, and the sum of the weights is equal to 1 (Malczewski 1999). The result of weighting is shown in Table 2. Regarding the importance of water resources in the area, the highest value was dedicated to groundwater, surface water resources and geology, respectively.

Aggregation criteria–land suitability map

The third and final step is producing the final landfill suitability map by overlaying the standardized maps. In this study, weighted linear combination (WLC) method was utilized to aggregate the maps. Since WLC is simple, possible in revision and ease of use in ArcGIS, it is the most common technique in multi-criteria decision analysis. This equation of this method is as follows:

$$S = \sum \mathrm{Wi} * \mathrm{Xi} \tag{1}$$

where Xi is standardized raster layers, Wi is layer's weight, and S shows the final map. All the standardized maps were combined according to the equation in ArcGIS10.2, and the final landfill suitability map was generated (Table 3).

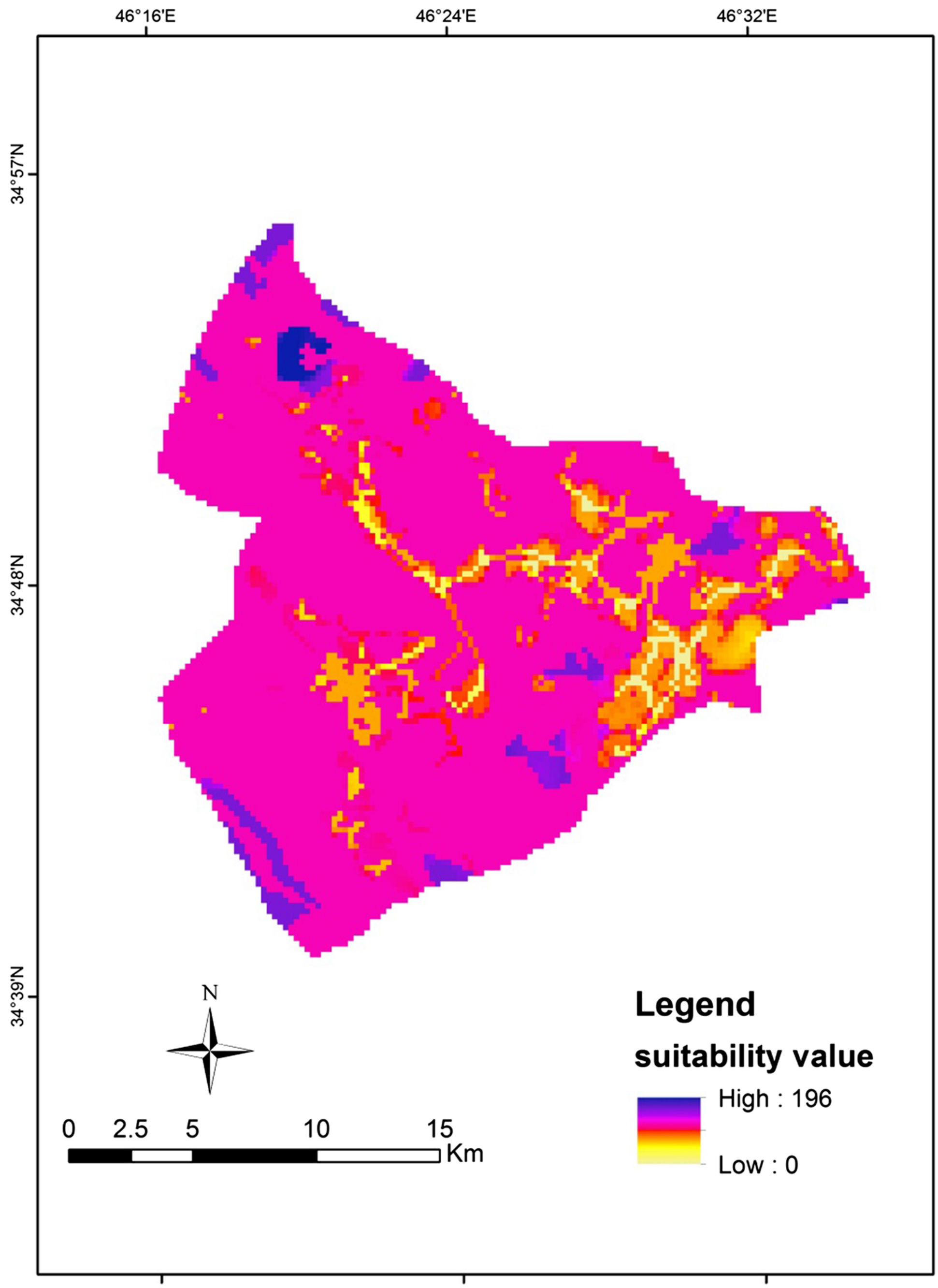

Fig. 6 Fuzzy suitability map for landfill

Results and discussion

The final map was prepared in fuzzy raster format, and its values range from 0 to 255 bytes. The regions with values over 196 bytes do not exist, and it indicates that the areas with very highly suitability are not present in the study area (Fig. 6). The final map was classified into four levels: unsuitable, low suitability, moderate suitability and high suitability (Fig. 7, Table 4). The land suitability map shows that 87% (35,567 ha) of the study area is not suitable, 6% (2590 ha) has low suitability, and other 7% (3023 ha) has moderate and high suitability for landfill sites. The suitable areas are patches mainly founded in the southeast and northwest of the study area.

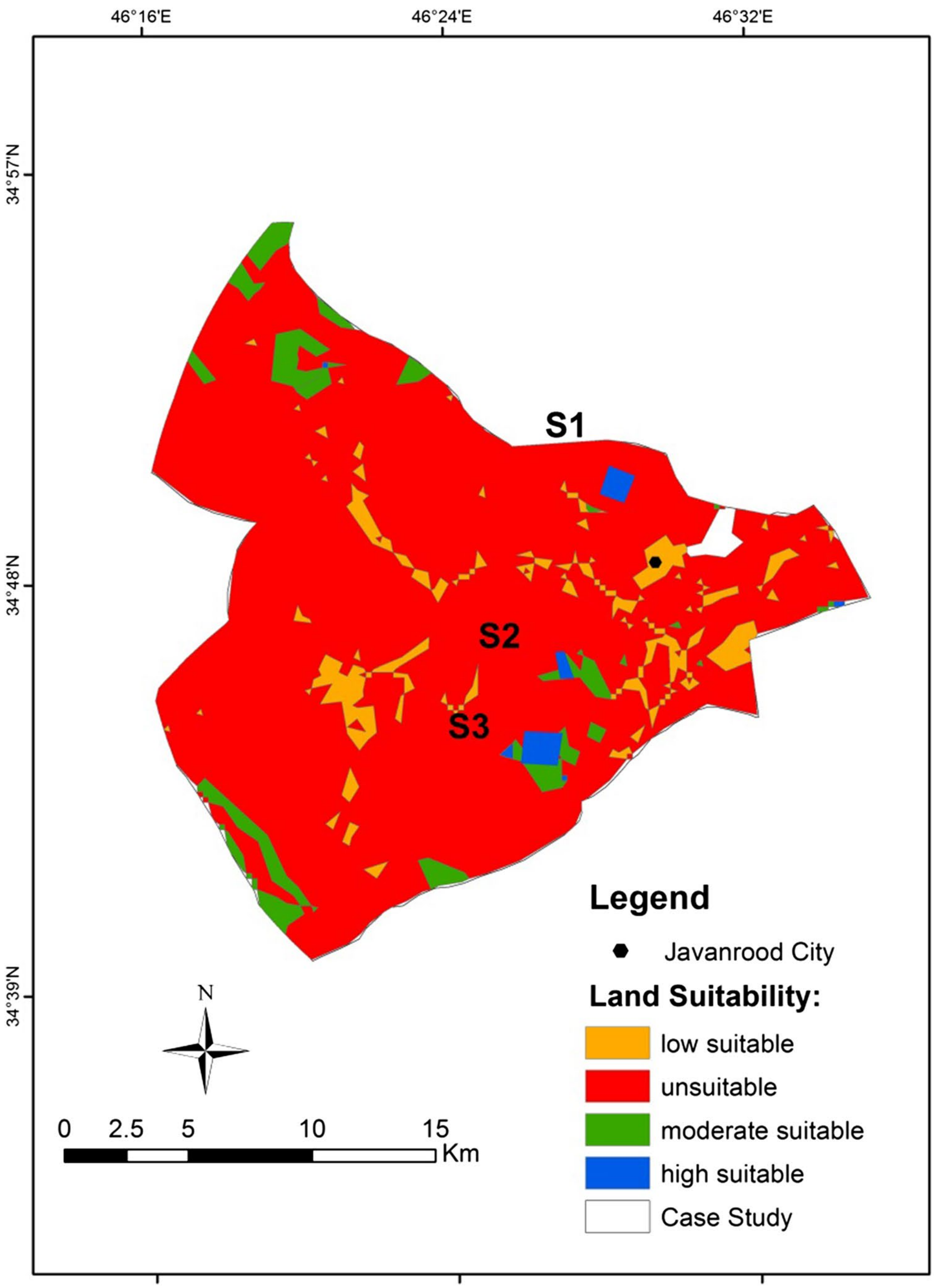

Fig. 7 Final landfill suitability map

Table 4 Suitability classes

Suitability class	Area (ha)	Area (%)
unsuitable	35,567	87
Low suitability	2590	6
Moderate suitability	2159	5
Highly suitability	864	2
Sum	43,180	100

Densely forest and steeper slopes of the mountain areas are the most critical constraints, resulting in reduced suitability of landfill in the study area. Also, the high density of the residential areas in lower slop areas raises this restriction. The presence of springs, faults and floodplains has lower effects on the whole area's inappropriateness for the establishment of the landfill. Because of the low table depth

Table 5 Characteristic of selected sites

Parameter	Site 1	Site 2	Site 3
Land use	Farm land-range	Range	Range
Geology	Kbgb	Trkurl	Trkurl
Soil texture	Loam	Loam-sandy	Loam-sandy
Distance to water surface (m)	1500	1400	900
Distance to groundwater resources (m)	500	1000	1800
Slope (%)	< 10	15–25	10–20
Wind direction	Western	Western	Southeastern
Distance to residential areas (m)	1100	700	1800
Distance to faults (m)	Intersect	< 5000	< 5000
Distance to aquifer (m)	< 2000	–	–
Distance to protect areas (km)	28	33	35
Acceptance	Acceptable	Pretty acceptable	Pretty acceptable
Land value	High	Low	Low
Distance to attractions (km)	< 2	< 4	< 10
Distance to roads	< 200	< 200	600
Distance to generation center (3 km)	3	6	8

of groundwater level in this area, there is no limitation for landfill from this point of view. Also, due to the lack of airport and historical places in the study area, these parameters were not constraints for suitability, and they were not considered in site selection. A significant part of the study area covers limestones, and this geological structure has weak potential because of high permeability. So the landfill sites need to place proper bedding in the bottom.

Considering the minimum area of 40 hectares for a 20-year period, only the patches which have an area over 40 hectares were chosen. Three candidate sites named S1, S2 and S3 (Fig. 7) were suggested for the landfill because these sites were placed in highly suitability regions. These sites have undeveloped lands, ideal distance to residential areas and, in addition, the lack of surface and groundwater resources nearby. Field checks were performed to check the suitability of these sites. The final site has been chosen by considering factors such as distance to generation points, wind direction, land property, soil for covering landfill cell, political issues, and public acceptance. The field checks have also confirmed the accuracy of the results for landfill siting.

Table 5 shows the characteristics of three selected sites regard to the environmental and economic criteria. According to the table, there are some limitations for all sites which need to consider mitigation measures to decrease negative impacts. The slope varies from 5 to up to 30% where site 1 is completely flat compared to other two sites. These sites also placed in a suitable distance from surface water sources. The unsuitable distance from underground water was considered 500 m. However, this distance in sites 2 and 3 were 1500 and 1800 m, respectively. In all sites, the distance from the protected areas was more than 7 km. They also were located in an acceptable distance to roads.

Various parameters in this study were selected for landfill site selection, and these parameters were made in a multi-criteria structure. These parameters were classed in two groups namely environmental criteria (distance to water resources, distance to groundwater resources, distance to protect areas, distance to faults, land use and aspect) and economic criteria (slope and distance to roads). As same as this research, similar studies were conducted and considered different criteria such as environmental criteria, economic and social criteria. For instance, Karimzadeh Motlagh and Sayadi (2015) and Kapilan and Elangovan (2018) investigated environment and economic criteria and the sub-criteria to select the best sites for landfill in different regions.

Weighted linear combination was used to create the landfill suitability map. This method is one of the most popular approaches in multi-criteria decision analysis. This method provides the possibility of criteria standardization in continues scales and thus has more flexibility compared to other techniques such as Boolean and Overlay. Also, in this method each factor assigns its particular weight and can be placed in a comparative range with other parameters. Studies conducted by researches such as Shahabi et al. (2013), Aydi et al. (2013) and Bahrani et al. (2016) showed that weighted linear combination is one of the best techniques in the landfill site selection. They indicated that in landfill site selection WLC had better decision-making powers compared to such MCDA methods as Boolean logic. However, Gorsevski et al. (2012), Karimzadeh Motlagh and Sayadi (2015) and Al-Anbari et al. 2018 used other MCDA methods such as ordered weighted average (OWA). They found that OWA has great potential and flexibility in the modeling of the complex decision-making problem.

Moreover, the results of this study in the capability of integrating GIS and MCDA in the landfill site selection are consistent with similar research. Gorsevski et al. (2012) and Vučijaka et al. (2016) concluded that a combination of GIS and multi-criteria evaluation methods has a great potential in locating a suitable place for a landfill. Likewise, Kharat et al. (2016), Yildirim et al. (2018) and Demesouka et al. (2013) found that the combination of GIS and MCDA has high ability in land suitability analysis for finding a suitable place for a landfill. Lokhande et al. (2017) in a study attempted to review various studies undertaken by researchers to implement multiple criteria decision analysis (MCDA) and geographical information system (GIS) in the procedure of selecting landfill site for any region. They found that various MCDA methods are reliable to use to find suitable locations for landfill for any geographical region.

Conclusion

The landfill site selection is a complex task required consideration of various criteria to select the ideal sites by integrated techniques. In this study, an analysis was conducted based on eight different parameters in environmental and economic groups. The integration of GIS and MCDA approach was used to select the best landfill sites. Regarding the fact that several factors are useful in site selection, the combination of GIS and MCDA simplifies the process of site selection, where GIS decreases the time and errors in analyzing and MCDA enhances the selection of parameters and options.

Considering various parameters reduces the environmental problems, economic costs and social conflicts. In this study, several factors from the national standards, information availability, literature reviews and local features were considered to locate suitable places for landfill sitting in the studied area. It is proposed in the future studies that such strategic and economic criteria such as political issue, future vision project, public utilities will be considered. However, the present study has the potential to be used for other regions with different data, due to the introduction of methodology and data analyses.

In conclusion, current disposal location of the city is not cost-effective and therefore a revision in their waste disposal strategy is necessary. The findings of this study give essential result to the policy makers and council in Javanrood City. After precise evaluations, three candidate sites were selected and the best one was identified based on the field checks and considering more parameters. Nevertheless, to enhance the efficiency of the results, undertaking a specific feasibility study in the area using the other parameters such as soil type, geotechniques features and also environmental impact assessment study is necessary to minimize all environmental pollution risks and enhance technical capabilities.

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Compliance with ethical standards

Conflict of interest Authors have no conflict of interest.

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